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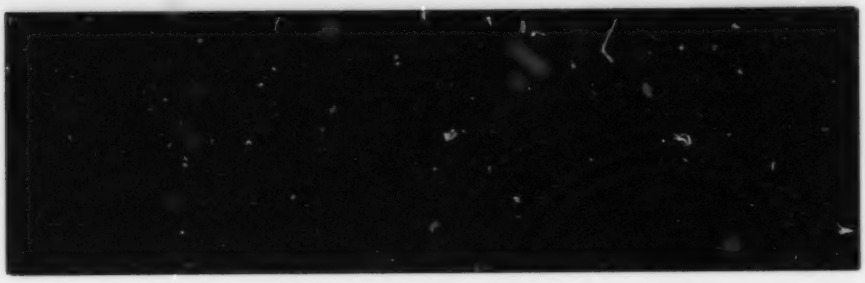

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REDUCTION OF RADON PROGENY CONCENTRATION BY MEANS OF AN AIR CLEANER

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REDUCTION OF RADON PROGENY CONCENTRATION BY MEANS OF AN AIR CLEANER

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ABSTRACT

The performance of an 'air-cleaner' for the control of radon (^{222}Rn) progeny in dwellings and in laboratory spaces has been investigated in a Radon/Thoron Test Facility (RTTF) of the walk-in type. The air cleaner consists basically of a fan and a special filter material sandwiched between two metal screens to which an electric field is applied. The filter is of the polarized media type and uses fibre glass as material. The fan and filter system are housed in a metal case. Air is drawn from the back of the case by means of the fan and forced through the 'electrical' filter where removal of ^{222}Rn progeny occurs. Radon-222 progeny 'depleted' air is discharged at the top of the device. Experiments were carried out in $^{222}Rn/^{222}Rn$ progeny atmospheres when the air cleaner was operating and when it was turned off. Very marked effects were observed during the operation of the air cleaner, namely: a very significant decrease in the Potential Alpha Energy Concentration (PAEC) and aerosol concentration, among other effects. The device has potential in industrial applications, which should be explored.

Key words: Reduction and control of radon progeny; Air cleaner; Electrostatic collection.

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RÉDUCTION DE LA CONCENTRATATION DES DESCENDANTS DU RADON AU MOYEN D'UN ÉPURATEUR D'AIR

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RÉSUMÉ

Le rendement d'un "épurateur d'air" pour éliminer les descendants du radon (^{222}Rn) dans les locaux des maisons et des laboratoires a été étudié dans une installation d'étude du radon et du thoron (IÉRT) de type chambre. L'épurateur consiste essentiellement d'un ventilateur et d'un matériau filtrant spécial serti entre deux grillages métalliques auxquels un champ électrique est appliqué. Le filtre est de la fibre de verre de type polarisé. L'emsemble ventilateur et filtre est logé dans un boîtier de métal. L'air est aspiré de l'arrière du boîtier par le ventilateur et soufflé sur le filtre "électrique" qui retient les descendants du ^{222}Rn. L'air "épuré" de ces descendants est rejeté par le dessus de l'appareil. Des expériences ont été menées dans des atmosphères chargées de ^{222}Rn et de ses descendants pendant que l'épurateur fonctionnait et pendant qu'il était à l'arrêt. Des effets très marqués ont été observés pendant le fonctionnement de l'épurateur, notamment une baisse considérable de la concentration d'énergie alpha potentielle (CÉAP) et de la concentrationn d'aérosol. L'appareil offre des possibilités d'application dans l'industrie qui devraient être explorées.

Mots clés: réduction et limitation des descendants du radon; épurateur d'air; piégeage électrostatique.

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INTRODUCTION

There are a variety of airborne radionuclides found in working and living environments which at sufficiently elevated concentration levels can pose a potential hazard to human health. Several methods and techniques have been devised to either control or reduce radioactive contaminants in air. In particular, forced mechanical ventilation, filtration, electrostatic deposition, turbulent air mixing by fans, and removal by ion-generators have been used, with varying degrees of success, in laboratory experiments or real life situations, to mitigate tne influence of the short-lived decay products of ^{222}Rn and ^{220}Rn (1-7).

A proper technological approach to the abatement of airborne radioactive pollutants should meet a number of important requirements, namely: the technique should be easy to use, inexpensive, effective, aesthetically acceptable, and should produce no secondary or 'side effects'.

The present communication describes the use of a device which operates on a 'hybrid' technique consisting of air filtration, electrostatic deposition, and turbulent air mixing to reduce the concentration levels of ^{222}Rn progeny levels in air. The device is potentially useful and promising in industrial applications, as well as in a variety of working and living environments.

DESCRIPTION OF THE DEVICE

The device ('air cleaner') distinguishes itself by its great mechanical and electrical simplicity. It consists basically of a mixing fan and a 'polarized media' filter made up of glass fibre material sandwiched between two metal grids (screens) to which an electrical field is applied. An electrical voltage difference of several thousand volts (V) is applied between the metal screens by means of an AC/DC converter, in conjunction with a DC multiplier. The alternating current (AC) to direct current (DC) converter,

converts 117 V from a conventional electrical outlet to a few V DC. The DC multiplier, in turn, converts the low voltage from the converter to a much higher signal to match the needs of the polarized media filter, i.e., several thousand volts.

The fan and the grids/filter system are housed in a metal case. Air is drawn by means of the fan from the back of the device through the 'electrified' filter and then exhausted at the top of the case. The fan can be operated at three different speeds. Figures 1 and 2 show the device, which is known under the commercial name: Electronic Air Cleaner Model CBB 1000, manufactured by CIMATEC Engineering Inc., Ottawa (Canada).

EXPERIMENTAL PROCEDURE

The device (air cleaner) was tested in a Radon/Thoron Test Facility (RTTF) of the walk-in type (8,9). Tests were conducted in $^{222}Rn/^{222}Rn$ progeny atmospheres.

The effect of the device on the following variables was investigated:

1. Non-radioactive aerosol concentration, N, and size distribution;
2. ^{222}Rn progeny concentration, i.e., Potential Alpha Energy Concentration PAEC(Rn), or WL(Rn), as well as $[^{218}Po]$, $[^{214}Pb]$, $[^{214}Po]$, and the disequilibrium ratios $[^{214}Pb]/[^{218}Po]$ and $[^{214}Po]/[^{218}Po]$. These variables were determined using the Thomas Tsivoglou method (10). (Note: square brackets are used here to indicate activity concentration.);
3. ^{222}Rn progeny unattached fractions (see below);
4. ^{222}Rn progeny plate-out on walls (using filter substrates on the RTTF walls); and
5. F-factors, defined by the ratio $PAEC(Rn)/[^{222}Rn]$.

Experiments were conducted at low aerosol concentrations ($N < 1000\ cm^{-3}$) and at moderate concentrations, i.e., $N \sim 1.0 \times 10^4\ cm^{-3}$.

The effect on items 1) to 5) was investigated when the air cleaner was

turned off, and when the device was operated according to the following operation schedule:

1. fan on with the filter removed;
2. fan on with the filter in place but no electric field applied to it;
3. fan on with the 'electrified' filter in place, i.e., with the filter in place and the electric field applied to it;
4. items 2 and 3 were repeated for several fan speeds.

In addition to the above tests, the β-particle activity corresponding to airborne ^{214}Pb and ^{214}Bi was monitored during several experiments by means of a β-particle probe of the pancake type Model HP-260 (manufactured by Eberline, U.S.A.), in conjunction with its associated electronic circuitry and data acquisition/processing system (11). Finally, temperature (T), and relative humidity (RH) were carefully noted during each experimental test.

ASSOCIATED (EXPERIMENTAL) EQUIPMENT USED

Dry ^{226}Ra sources of the flowthrough type, model Rn-1025 (manufactured by Pylon Electronic Development, Ottawa, Canada), were used to produce ^{222}Rn and its progeny in the RTTF. Aerosols were injected into the RTTF using aqueous solutions of uranin in conjunction with an aerosol atomizer, and associated air supply system, model 3076 manufactured by TSI (U.S.A.). Aerosol concentration and aerosol size distribution were measured by means of a condensation nuclei counter (CNC, model 3020) and a Differential Mobility Particle Sizer (DMPS, model 3071). Both, the CNC and the DMPS were manufactured by TSI (U.S.A.).

Aerosols (uranin) and ^{222}Rn were premixed in a special chamber before being injected into the RTTF through the air injection distribution system.

Unattached ^{222}Rn progeny fractions were determined using the mesh method (12-14), according to procedures indicated elsewhere (15), and specially designed screen-filter/filter holder systems of the open face type.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental data obtained during the air cleaner tests are shown in Tables 1 to 4 and Figures 3 to 17. A few rapid trial tests were conducted with the air cleaner, with a twofold purpose in mind, namely:

1. To get an indication of the effectiveness of the device as a ^{222}Rn progeny 'remover'; and
2. To help, with item 1 in mind, in the design of a more rigorous and comprehensive test program.

The results of the preliminary tests indicated in item 1 have been summarized in Table 1. This Table shows the effect of the air cleaner on the following variables: WL(Rn), $[^{214}Pb]/[^{218}Po]$(-F1), $[^{214}Bi]/[^{218}Po]$(-F2), aerosol concentration (N), and β-particle count (N_β). The tests were conducted under the following conditions:

$$[^{222}Rn] \sim 160\ pCiL^{-1}\ (5.92 \times 10^3\ Bqm^{-3})$$

$$T \sim 20^oC$$

$$RH \sim 60\%$$

The RTTF was operated on a 100% recirculating airflow mode at an airflow rate of 4 m^3min^{-1}.

Table 1 shows the following features of interest in the context of this investigation:

1. All the variables measured decreased either drastically or significantly when the air cleaner was operated (fan on, and filter in place with electric field applied to it) relative to the case when the cleaner was turned off;
2. The effect indicated in item 1 was significantly more pronounced when tests were initiated at higher aerosol concentration (N), i.e., $N > 1.0 \times 10^4$ cm^{-3}, than at lower N, i.e., $N \leq 1.0 \times 10^3$ cm^{-3};
3. As expected, $[^{222}Rn]$ was not affected by the operation of the air cleaner. However, because WL(Rn), or PAEC(Rn), was markedly affected by it, the F-

value (defined by $F = WL(Rn) \times 10^2 / [^{222}Rn]$) was dramatically affected by the air cleaner. For example, for $N \sim 1.2 \times 10^4$ cm^{-3} a tenfold decrease in F was observed, i.e., from 0.58 to 0.06 during operation of the air cleaner. As will be shown later, the decrease in the F-value is caused by the plate-out of ^{222}Rn progeny on the RTTF walls, and other large surfaces;

4. The air cleaner is effective in removing non-radioactive aerosol as well as radioactive aerosol. It also seems to affect the aerosol size distribution as will be shown below;
5. ^{214}Pb and ^{214}Bi (^{214}Po) are more readily removed from the air than ^{218}Po when the air cleaner is operated. However, ^{214}Bi (^{214}Po) are removed from air even more readily than ^{214}Pb. These effects seem to be more pronounced when tests are conducted at higher aerosol concentration than at lower concentration. The question whether the above airborne radionuclides are removed from air by plate-out mechanisms on large surfaces, or by electrostatic deposition will be examined later; and
6. Table 1 also shows that the ratio $F1/F2 = [^{214}Pb]/[^{214}Po]$ increases significantly when the air cleaner is operating as compared with the same ratio when the device is turned off, i.e., F1/F2 = 1.56 (OFF) and F1/F2 = 6.0 (ON) for low aerosol concentrations ($N < 1.0 \times 10^3$ cm^{-3}); and F1/F2 = 1.38 (OFF) for $N \sim 1.2 \times 10^4$ cm^{-3} and F1/F2 = 10.0 (ON) for low N. Since $[^{214}Pb]$ and $[^{214}Bi]$($[^{214}Po]$) are reduced during the operation of the air cleaner, the results indicated above suggest that $[^{214}Po]$ and $[^{214}Bi]$ are reduced at a faster, or more accelerated rate, than $[^{214}Pb]$. As the data show, this effect seems to be more pronounced for moderate N than for low N.

Items 1 to 6 provided a wealth of information on which more experimental tests were based. Hence, a more rigorous and exhaustive series of measurements followed the above initial test trials. The results of these latter tests are given in Tables 2 to 4 and Figures 3 to 17. Because of the

complexity of the subject, the data obtained (under a number of experimental conditions) will be divided into several sections according to the effect induced by the air cleaner on each of the variables investigated.

A. EFFECT ON AEROSOL CONCENTRATION AND AEROSOL SIZE DISTRIBUTION

As previously discussed in the first series of measurements, subsequent measurements confirmed that the aerosol concentration in the submicron size range diminished markedly under the influence of the air cleaner (fan speed at medium position, and filter in place with electric field applied to it). Figures 3 and 4 show two typical examples of this behaviour. Furthermore, aerosol size distribution measurements indicated that the geometric mean of the aerosol size distribution (i.e., geometric mean of the aerosol diameter distribution) decreased significantly (10% to ~20%) under the effect of the air cleaner, i.e., from ~0.13 μm to ~0.11 μm. A point of interest should be noted, namely, the tendency of the aerosol cloud to retain its original size distribution. In other words, after a marked transient effect (i.e., reduction of the geometric mean), the geometric mean of the distribution started to increase slowly somewhat in what seems to be an 'effort' to preserve its initial size distribution state before operating the air cleaner. Figure 5 shows the effect of the air cleaner on the aerosol size distribution.

The result of numerous measurements show that the air cleaner brought about up to a 25-fold decrease in the aerosol concentration in the RTTF.

B. EFFECT ON RADON (^{222}Rn) AND RADON PROGENY

The ^{222}Rn concentration, [^{222}Rn], was unaffected by the operation of the air cleaner. This was expected because of the chemical inertness and molecular size of this radionuclide. The air cleaner had, however, a considerable effect on the PAEC(Rn), i.e., WL(Rn), and the short-lived decay products of ^{222}Rn, namely, ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po.

Table 2 shows some of the data obtained during the second series of

experiments in the RTTF. Also indicated in the Tables are the operating conditions of the air cleaner. The data of Table 2 are better visualized in Figures 6 to 11. Each of these Figures show six continuous lines (separated from each other by an arbitrary 'length' of time for simplicity), for each variable. Because of the strong (direct) relationship between the several variables in the above graphs, the daily profiles shown in Figures 6 to 11, for the different variables, and for a given day, are very similar. The substantial changes in value for the different variables are in all cases related to the operation, or lack thereof, of the air cleaner, as indicated by the vertical arrows.

Because the operation of the air cleaner affected the ^{222}Rn progeny concentrations, and their disequilibrium ratios, as well as the 'normal' aerosol concentration, N, it is of interest to study the relationships between $[^{218}Po]$, $[^{214}Pb]$ and $[^{214}Po)$, and N, and between $[^{214}Pb]/[^{218}Po]$ = F1, or $[^{214}Po]/[^{218}Po]$ = F2 and N. These relationships are shown graphically in Figures 12 and 13, respectively. Data were analyzed by the Least Squares Method (LSM). The results of these analyses show that straight lines of positive slope (correlation coefficient, CC >0.9) best seemed to fit the experimental data. It should be noted that this does not prove that there is indeed a strict linear relationship between the ^{222}Rn progeny, F1, F2, and the aerosol concentration, N. It merely indicates that the linear function fits the experimental data well. A similar analysis to that carried out above, but between PAEC(Rn) and N shows that there is also a linear relationship between these two variables (see Figure 14). This is hardly surprising because PAEC(Rn) is in fact a linear function of $[^{218}Po]$, $[^{214}Pb]$, and $[^{214}Po]$, namely: $PAEC(Rn) = a[^{218}Po] + b[^{214}Pb] + c[^{214}Po]$, where a, b and c are 'fixed' numerical coefficients.

The fact that the disequilibrium ratios F1 and F2 are also linearly related to the aerosol concentration N is again not surprising because

[^{218}Po], [^{214}Pb], and [^{214}Po] are, to a first order, linearly related to N according to Figure 12, and the concentrations of these three airborne radionuclides increase or decrease at the same rate, within experimental error, with increasing or decreasing N, respectively. Measurements at low aerosol concentrations are particularly difficult because of significant measuring errors and poor counting statistics of N, and ^{222}Rn progeny.

In summary, the data presented in this section seem to support the notion that, within experimental error, the PAEC(Rn), the ^{222}Rn progeny concentrations, and their disequilibrium ratios F1 and F2, vary linearly (or nearly linearly) with aerosol concentration within the approximate aerosol concentration range 500 $cm^{-3} \leq N < 2.6 \times 10^4$ cm^{-3}.

C. EFFECT ON THE PLATE-OUT OF ^{222}Rn PROGENY ON THE RTTF WALLS

Recently formed ^{222}Rn progeny readily attach themselves to aerosols. This attachment results in a decrease in the diffusibility of ^{222}Rn progeny, and hence, in a decrease in the probability of plating-out on large surfaces. However, when the physical space is depleted of aerosols, the ^{222}Rn progeny find no substrata to attach to, and hence, they plate-out readily on walls and other large surfaces.

Because the operation of the air cleaner has proved to be quite effective in removing aerosols from the RTTF, it should be no surprise to measure a significant increase in the plate-out of ^{222}Rn progeny on the RTTF walls when the device is in operation. This has, indeed, been the case as Figures 14 and 15 show. Figure 14 shows that the α-particle activity measured on 'samples' placed on the RTTF walls decreases rapidly with increasing aerosol concentration. The reason for this behaviour is quite simple, as explained above, namely, an increase in aerosol concentration simply means more particles available for the ^{222}Rn progeny to attach to. This, in turn, causes a decrease in the radioactive aerosols diffusibility because of their augmented size, and hence, a lower probability of plating-out on walls and

other large surfaces. The reverse mechanism holds equally true.

Although according to the LSM referred to above, Figure 14 shows a linear relationship between the α-particle plate-out activity, $N_\alpha(P/O)$, and the aerosol concentration N, it should be stressed that the correlation coefficient obtained for this case was not particularly high, i.e., C.C. <0.9. This suggests that this linear relationship may only be a crude approximation of a more subtle relationship. Although time constraints did not allow for further experimental elaboration on this point, the data could conceivably better fit, in a first order approximation, a line with two or more plateaus as shown in Figure 15. However, this contention is at this point somewhat speculative and will necessitate further experimentation. The experimental data shown in these Figures also indicate that a saturation condition is reached, namely, $N_\alpha(P/O)$ increases with increasing aerosol concentration (N), more rapidly at first for low N, and more slowly afterwards for higher values of N until eventually a further increase in aerosol concentration does not bring about any significant decrease in the ^{222}Rn progeny activity plated-out on the RTTF walls. This relationship, indicated in Figure 15 by the broken line graph, is the more likely explanation for the observed data and is consistent with the present physical situation.

Finally, the relationship between the ^{222}Rn progeny activity plated-out on the RTTF walls and the progeny disequilibrium ratios $[^{214}Pb]/[^{218}Po]$ = F1 and $[^{214}Po]/[^{218}Po]$ = F2 was investigated. The results are shown in Figures 16 and 17. These graphs show an approximately linear relationship, with negative slope (i.e., inverse linear relationship) between $N_\alpha(P/O)$ and F1 and F2. The behaviour observed between these three variables can be explained as follows. An increase in, or large values for, F1 and F2 indicate a tendency of ^{222}Rn progeny towards radioactive equilibrium conditions. This situation occurs when two physical conditions are met, namely:

1. Long residence time (RT) of ^{222}Rn progeny in the vessel or volume of

interest, e.g., RTTF; and

2. No selective removal, e.g., plate-out, of ^{222}Rn progeny in the RTTF.

The reverse of item 2, i.e., selective removal of ^{222}Rn progeny may occur at low aerosol concentrations, say by the influence of a mixing fan, electrostatic deposition, or the effect of an ion-generator (2). Long, or relatively long, RT is also partly applicable to the present case because the RTTF has been operated in these experiments at an airflow rate of 4 $m^3 min^{-1}$ in a recirculating mode. Hence, on the basis of the above observations, the inverse relationship between $N_\alpha(P/O)$, and F1 and F2 is to be expected. The following example will clarify the above situation: low values for F1 and F2 indicate large radioactive disequilibrium states of the ^{222}Rn progeny and high unattached ^{222}Rn progeny fractions which, as is well known, will favour their removal by plate-out mechanisms on large surfaces such as the RTTF walls. Table 3 shows complementary data pertaining to plate-out rates, aerosol concentration, and the operating conditions of the air cleaner, among other things. The data on this Table will be useful in further discussions and is relevant to preceding arguments.

D. EFFECT ON THE ^{222}Rn PROGENY UNATTACHED FRACTIONS

The unattached ^{222}Rn progeny fractions, f_u, were determined during the operation of the air cleaner, and when the device was turned off. The results obtained for ^{218}Po and PAEC(Rn) are given in Table 4.

As indicated in the previous section, the ^{222}Rn progeny plated-out on large surfaces such as vessel walls, and other surfaces, is very dependent on the aerosol concentration and the aerosol size distribution. The ^{222}Rn progeny fraction that plates-out more readily is the 'unattached' fraction, f_u, i.e., ^{222}Rn progeny that do not 'combine' or attach to other aerosols either because of aerosol size distribution considerations or because of the absence of aerosols. Furthermore, because the air cleaner has proved to be quite effective in removing aerosols from air, operation of this device is

expected to have a significant influence on both plate-out mechanisms and on its direct precursor, namely, the unattached ^{222}Rn progeny fractions.

The experimental data of Table 4 shows the following items:

1. Very low unattached fractions (1% to 3%) were measured when the air cleaner was not in operation. This result is consistent with the relatively high aerosol concentration ($N \sim 2.0 \times 10^4$ cm^{-3}) present during the duration of the experiment. This concentration remained essentially constant and its size distribution undisturbed because the air cleaner was not operating.
2. When the air cleaner filter was removed and only the fan was operated, a slight increase in the unattached fractions, f_u, was measured.
3. The unattached fractions increased significantly (3% to 9%) when the air cleaner was operated with the fan on and the filter in place, but with no electric field applied to it.
4. A dramatic increase in the values of f_u (32% to 40%) was measured when the air cleaner was operated in its conventional mode of operation, namely, with the fan on, and the filter in place with the electric field applied to it.

The results presented in this section and the previous one (section C) clearly show the concurrent behaviour of the unattached ^{222}Rn progeny fractions, f_u, and the ^{222}Rn progeny plate-out, $N_\alpha(P/O)$, on the RTTF walls. The reasons for this behaviour have been discussed above.

E. EFFECT ON THE F-FACTOR

The F-factor has been defined before as the ratio: $F = (WL(Rn)/[^{222}Rn])\times 10^2$, where $[^{222}Rn]$ is given in $pCiL^{-1}$. From the definition of WL(Rn), it is clear that the F-factor can only have values ranging from 0 to 1, i.e., $0 \leq F \leq 1$. It has also been pointed out that this air cleaner has no effect on the ^{222}Rn concentration because it does not use activated carbon, or other similar compound, to adsorb it. However, the WL(Rn) is significantly

affected by the operation of the air cleaner, as shown and discussed in Section B, and consequently the F-factor is affected through WL(Rn). It is a simple matter to calculate the range of values for the F-factor, in other words, the change in the value of the F-factor brought about by the operation of the air cleaner. From Table 2, the range of values found for the F-factor was: $0.025 \leq F \leq 0.58$. The low values for the F-factor were those obtained when the air cleaner was operating.

SOME PRACTICAL OBSERVATIONS AND THEORY OF ^{222}Rn PROGENY REMOVAL BY THE AIR CLEANER

It is important to note that the effect of the air cleaner on its immediate environment was tested by placing the device in a Radon/Thoron Test Facility (RTTF) of the walk-in type. In this configuration, the air cleaner will operate satisfactorily for the control and reduction of ^{222}Rn progeny in dwellings. More specifically, the unit will be quite efficient for air quality control purposes in rooms of medium to, perhaps, large size. For industrial applications, however, the device should be modified accordingly by, for example, removing its fan and placing the unit directly in the ventilation ducting. Because the filter used offers little resistance to the flow of air, there seems to be not much problem in using more than one unit in series in the ventilation network.

The principle of operation that makes the air cleaner so effective in removing ^{222}Rn progeny is fairly simple as indicated below. From inspection of the experimental data and the device itself it becomes immediately obvious that:

1. The filter is too 'coarse' and cannot remove much particulate matter in the submicron size range by itself by simple mechanical filtration without 'external help'. In other words, the filter alone is very inefficient at removing radioactive and non-radioactive aerosol in the ^{222}Rn progeny size range, i.e., approximately 0.05 μm to ~0.2 μm.

2. The operation of the air cleaners' fan alone, i.e., filter removed, is efficient in removing ^{222}Rn progeny from air by plate-out on nearby large surfaces such as the RTTF walls. Plate-out of aerosols in the submicron range is caused by the strong convection air currents set up by the mixing fan (2,4).

3. Although the fan in the air cleaner contributes significantly to the removal of non-radioactive and radioactive aerosols alike, the major contribution to ^{222}Rn progeny removal arises from the operation of the air cleaner when the filter is in place and an electric field is applied to it. In its simplest operational version, the electric field applied to the filter removes electrically charged particles, ^{222}Rn progeny or otherwise, passing through the screens/filter system. Furthermore, when the electrical potential applied to the electrodes is high enough, an electrical charge can be induced in neutral particles which can then be removed, as indicated above. However, in the present case, the special filter used in the air cleaner is of the 'polarized media' type. The filter material is fibre glass, a dielectric material, which becomes electrically polarized when an external electric field is applied to it, resulting in positive and negative charges being induced on the surfaces of the dielectric material. Aerosols entering the electric field between the metal screens 'sandwiching' the filter also become polarized. The dual polarization of fibre glass fibres and aerosols causes the aerosols (e.g., ^{222}Rn progeny) to adhere to the fibres.

It is not clear whether the depletion of aerosols that accompanies, or causes, the removal of ^{222}Rn progeny from the volume of interest (brought about by the operation of the air cleaner) can induce, in turn, some biological effect in humans in the long-term, or cause immediate discomfort by upsetting the electric charge balance in air, or any other effect. This subject is, however, beyond the scope of this communication.

CONCLUSIONS

The air cleaner was quite efficient in removing ^{222}Rn progeny from a Radon/Thoron Test Facility (RTTF) of the walk-in type where the testing device was located. The RTTF was operated at an airflow rate of 4 $m^3 min^{-1}$ in a 100% recirculating mode with continuous injection of ^{222}Rn and submicron aerosol. The major conclusions of this study are:

1. The fan alone, i.e., filter removed from the air cleaner, produced a slight increase in the unattached ^{222}Rn progeny fractions, f_u, and a significant increase in the ^{222}Rn progeny plated-out on the RTTF walls, which was caused by turbulent air mixing by the fan.
2. The air cleaner operating with the filter in place, and the electric field applied to it (i.e., normal way of operation) induced drastic reductions in: PAEC(Rn), individual ^{222}Rn progeny concentrations, ^{222}Rn progeny disequilibrium ratios, F-factor, and aerosol concentration. Furthermore, the particle size geometric mean of the aerosol cloud was reduced by about 10% to 20% by the operation of the air cleaner.
3. In addition to the effects listed in item 2, operation of the air cleaner caused a large increase in the unattached fractions and the plate-out of ^{222}Rn progeny on the RTTF walls.
4. The air cleaner had no effect on the ^{222}Rn concentration level.

Some of the values of the variables indicated above either were reduced or increased by an order of magnitude, or more, depending on the variable itself, and the operating conditions of the air cleaner.

There is great potential for this type of air cleaner in industrial applications. In these applications, the device should be modified accordingly, e.g., the fan could be removed from the case and the unit fitted directly to the ventilation ducting. Alternatively, a frame to hold the filter/metal screens system in place can be designed to fit, leakfree, the

ventilation ducting. This technology could easily be adopted by, and adapted to, the mining industry.

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Table 1 - Effect of the air cleaner on some important variables

Date 1990	N_α (cpm)	N (cm^{-3})	WL(Rn)	$\frac{[^{214}Pb]}{[^{218}Po]}$ - F1	$\frac{[^{214}Bi]}{[^{218}Po]}$ - F2	R_β	R_N	R_{WL}	R_{F1}	R_{F2}	Air Cleaner
July 19	~1000	400-500	-	-	-	-	-	-	-	-	OFF
	500	200	-	-	-	2.00	~2.00	-	-	-	ON
July 20	1270	380	0.24	0.25	0.16						OFF
	450	150	0.07	0.06	<0.01	2.82	2.53	3.43	4.16	>16.0	ON
July 23	4000	12000	0.93	0.69	0.50						OFF
	750	600	0.10	0.10	<0.01	5.33	20.0	9.30	6.90	>50.0	ON

Notes: 1) Setting of air cleaner fan is medium airflow rate.

2) The values given above are average values from several independent tests. Values for N_β have not been corrected for background.

3) $[^{222}Rn]$ ~160 $pCiL^{-1}$ (5.92×10^3 Bqm^{-3}).

4) The symbol R_X is defined as the ratio of the value corresponding to the variable X obtained when the air cleaner is off to the value when the device is on.

Table 2 - Grab samples (Thomas)

Date	Time	[218Po] pCi/L	[218Po] Bq/m3	[214Pb] pCi/L	[214Pb] Bq/m3	[214Bi] pCi/L	[214Bi] Bq/m3	WL(Rn)	PAEC(Rn) (mJ/m3)	[214Pb]/[218Po]	[214Bi]/[218Po]	Air Cleaner
Jul 20 90	833	82.14	3039.00	20.85	771.50	13.14	486.04	0.24	4.98	0.254	0.160	off
	1046	51.84	1918.21	2.95	109.24	0.25	9.39	0.07	1.44	0.057	0.005	on
	1525	87.36	3232.47	14.21	525.62	9.06	335.21	0.20	4.07	0.163	0.104	off
Jul 23 90	815	57.02	2109.72	7.13	263.99	5.35	197.83	0.11	2.39	0.125	0.094	off
	936	159.07	5885.68	69.23	2561.38	31.01	1147.22	0.63	13.12	0.435	0.195	off
	1030	144.23	5336.42	100.18	3706.79	72.23	2672.48	0.93	19.27	0.695	0.501	off
	1130	61.13	2261.97	6.76	249.94	2.33	86.08	0.11	2.20	0.110	0.038	on
	1230	63.97	2366.97	6.98	258.23	0.03	0.97	0.10	2.11	0.109	0.000	on
	1330	61.93	2291.39	6.28	232.46	0.73	27.01	0.10	2.05	0.101	0.012	on
	1415	134.35	4971.10	51.03	1887.99	28.61	1058.43	0.50	10.48	0.380	0.213	off
	1500	139.50	5161.53	85.52	3164.19	67.03	2480.02	0.83	17.22	0.613	0.480	off
Sep 13 90	929	111.50	4125.38	65.68	2430.14	44.62	1650.79	0.61	12.79	0.589	0.400	off
	1030	97.23	3597.34	69.28	2563.43	60.88	2252.67	0.68	14.12	0.713	0.626	off
	1109	98.38	3639.97	71.60	2649.24	62.33	2306.39	0.70	14.51	0.728	0.634	off
	1244	121.33	4489.32	75.84	2806.26	58.31	2157.62	0.73	15.13	0.625	0.481	off
	1334	44.41	1643.34	5.77	213.31	0.50	18.35	0.08	1.60	0.130	0.011	on
	1410	36.71	1358.38	4.73	175.03	1.50	55.36	0.07	1.40	0.129	0.041	on
	1525	91.17	3373.47	60.12	2224.47	31.53	1166.58	0.52	10.75	0.659	0.346	off
Sep 14 90	818	99.36	3676.32	76.11	2815.93	65.44	2421.16	0.73	15.24	0.766	0.659	off
	905	89.09	3296.24	76.50	2830.35	63.88	2363.61	0.7?	14.94	0.859	0.717	off
	936	117.52	4348.26	78.49	2904.19	59.54	2203.01	0.74	15.43	0.668	0.507	off
	1102	56.14	2077.04	11.68	432.15	0.84	30.95	0.12	2.50	0.208	0.015	on
	1133	43.57	1612.05	4.39	162.57	1.51	56.00	0.07	1.51	0.101	0.035	on
	1300	40.59	1501.89	4.71	174.28	1.82	67.45	0.07	1.51	0.116	0.045	on
	1430	100.99	3736.49	51.34	1899.44	22.69	839.65	0.45	9.34	0.508	0.225	off
	1532	110.29	4080.74	68.18	2522.53	50.17	1856.36	0.65	13.45	0.618	0.455	off
Sep 18 90	840	109.76	4060.97	76.42	2827.60	61.93	2291.55	0.73	15.23	0.696	0.564	off
	1022	129.99	4809.77	83.94	3105.72	54.45	2014.73	0.76	15.87	0.646	0.419	off
	1235	30.34	1122.46	3.14	116.18	1.91	70.66	0.05	1.13	0.104	0.063	on
	1410	36.13	1336.70	3.31	122.65	0.51	18.79	0.06	1.16	0.092	0.014	on
Sep 19 90	810	115.38	4269.11	84.11	3112.01	63.39	2345.58	0.78	16.27	0.729	0.549	off
	822	115.50	4273.68	83.56	3091.54	66.70	2468.07	0.79	16.47	0.723	0.578	off
	932	46.00	1702.08	5.06	187.35	1.77	65.58	0.08	1.66	0.110	0.039	low
	1029	51.10	1890.82	5.79	214.22	1.88	69.73	0.09	1.85	0.113	0.037	
	1130	42.33	1566.12	6.00	221.87	0.06	2.09	0.07	1.54	0.142	0.001	medium
	1247	30.23	1118.59	2.13	78.98	4.35	161.06	0.06	1.21	0.071	0.144	
	1335	43.04	1592.52	3.43	126.82	0.25	9.19	0.06	1.30	0.080	0.006	high
	1425	30.79	1139.12	2.22	82.20	0.24	8.78	0.04	0.91	0.072	0.008	
Sep 20 90	833	35.61	1317.60	3.40	125.83	-1.33	-49.34	0.05	1.02	0.096	-0.037	high
	932	28.20	1043.45	2.91	107.69	0.09	3.17	0.04	0.92	0.103	0.003	
	1103	79.94	2957.72	29.38	1087.03	8.61	318.56	0.26	5.48	0.368	0.108	high
	1148	93.18	3447.64	42.17	1560.21	24.07	890.57	0.40	8.32	0.453	0.258	no filter
	1338	103.01	3811.26	68.18	2522.71	40.75	1507.89	0.60	12.57	0.662	0.396	off
	1438	109.77	4061.48	71.75	2654.65	57.51	2127.76	0.69	14.39	0.654	0.524	
Sep 21 90	805	103.38	3824.97	57.87	2141.03	37.48	1386.87	0.54	11.23	0.560	0.363	high
	940	114.06	4220.10	60.40	2234.80	34.69	1283.50	0.55	11.51	0.530	0.304	no filter
	1044	89.27	3302.98	31.39	1161.47	14.93	552.27	0.31	6.38	0.352	0.167	high
	1132	73.60	2723.25	27.33	1011.24	11.16	413.09	0.26	5.33	0.371	0.152	filter
	1325	32.34	1196.65	1.74	64.49	0.25	9.17	0.04	0.90	0.054	0.008	high
	1422	32.46	1201.06	2.00	73.86	0.34	12.44	0.04	0.93	0.061	0.010	filter

Table 3 - Air cleaner data

Date	PAEC(Rn) (uJ/m3)	N cm-3	stdv	N_{ot}(P/O) DPM	stdv	[218Po] (Bq/m3)	[214Pb] (Bq/m3)	[214Po] (Bq/m3)	[214Pb] / [218Po]	[214Po] / [218Po]	Air Cleaner	Filter	Charge
Sep 18	15.23	21675	1247	13.49	1.54	4060.97	2827.60	2291.55	0.696	0.564	off	—	—
	15.87					4809.77	3105.72	2014.73	0.646	0.419			
	1.13	1330	76	27.53	2.75	1122.46	116.18	70.66	0.104	0.063	on(med)	yes	yes
	1.16					1336.70	122.65	18.79	0.092	0.014			
Sep 19	1.66	1838	104	24.82	1.72	1702.08	187.35	65.58	0.110	0.039	on(low)	yes	yes
	1.85					1890.82	214.22	69.73	0.113	0.037			
	1.30	398	58	24.16	2.49	1592.52	126.82	9.19	0.080	0.006	on(high)	yes	yes
	0.91					1139.12	82.20	8.78	0.072	0.008			
Sep 20	1.02	360	86	25.50	3.85	1317.60	125.83	-49.34	0.096	-0.037	on(high)	yes	yes
	0.92					1043.45	107.69	3.17	0.103	0.003			
	5.48	10525	2303	16.82	3.24	2957.72	1087.03	318.56	0.368	0.108	on(high)	no	no
	8.32					3447.64	1560.21	890.57	0.453	0.258			
	12.57	19513	2168	10.06	2.11	3811.26	2522.71	1507.89	0.662	0.396	off	—	—
	14.39					4061.48	2654.65	2127.76	0.654	0.524			
Sep 21	11.23	16000	0	17.41	2.86	3824.97	2141.03	1386.87	0.560	0.363	on(high)	no	no
	11.51					4220.10	2234.80	1283.50	0.530	0.304			
	6.38	6707	657	15.17	1.82	3302.98	1161.47	552.27	0.352	0.167	on(high)	yes	no
	5.33					2723.25	1011.24	413.09	0.371	0.152			
	0.90	690	175	26.63	7.92	1196.65	64.49	9.17	0.054	0.008	on(high)	yes	yes
	0.93					1201.06	73.86	12.44	0.061	0.010			

Table 4 - ^{218}Po and PAEC(Rn) unattached fractions for several air cleaner operating conditions

$f_u(^{218}Po)$	f_u(PAEC)	Air Cleaner	Fan	Filter	Charge	Fan Speed
~0.03	0.01	OFF	OFF	ON	OFF	OFF
0.04	0.02	ON	ON	OFF	OFF	HIGH
~0.09	~0.03	ON	ON	ON	OFF	HIGH
0.40	0.32	ON	ON	ON	ON	MEDIUM; HIGH

Notes: *Average values calculated for the air cleaner operating at medium and high fan speeds.

a) the symbol f_u is used to indicate unattached fraction. To obtain the percentage (%) unattached fraction, multiply the above figures by 100.

b) the attached fraction f_a is obtained from the relationship: $f_a = 1 - f_u$.

c) all the experiments were conducted starting with aerosol concentrations of about 2×10^4 cm^{-3}.

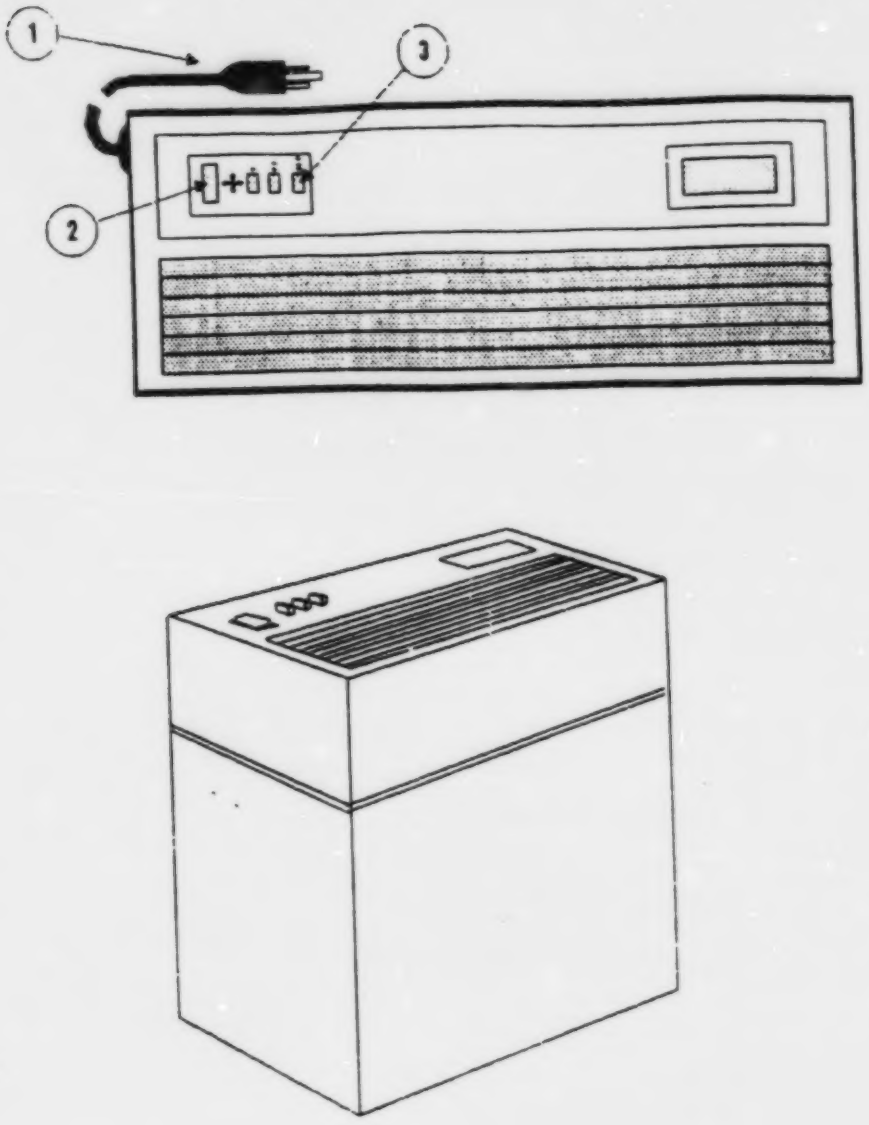

Fig. 1 - Air cleaner: top view (upper drawing), and side view (lower drawing).

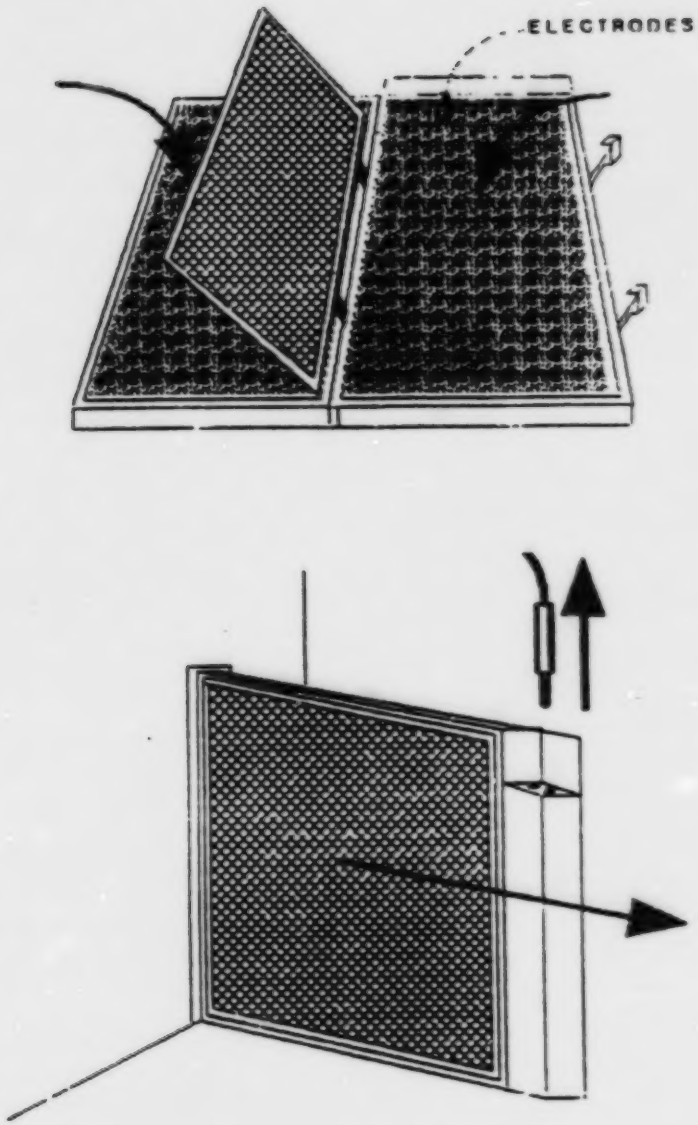

Fig. 2 - Details of the filter/screens system: screens open (upper drawing), and system mounted ready to be installed in the metal case of the air cleaner (lower drawing).

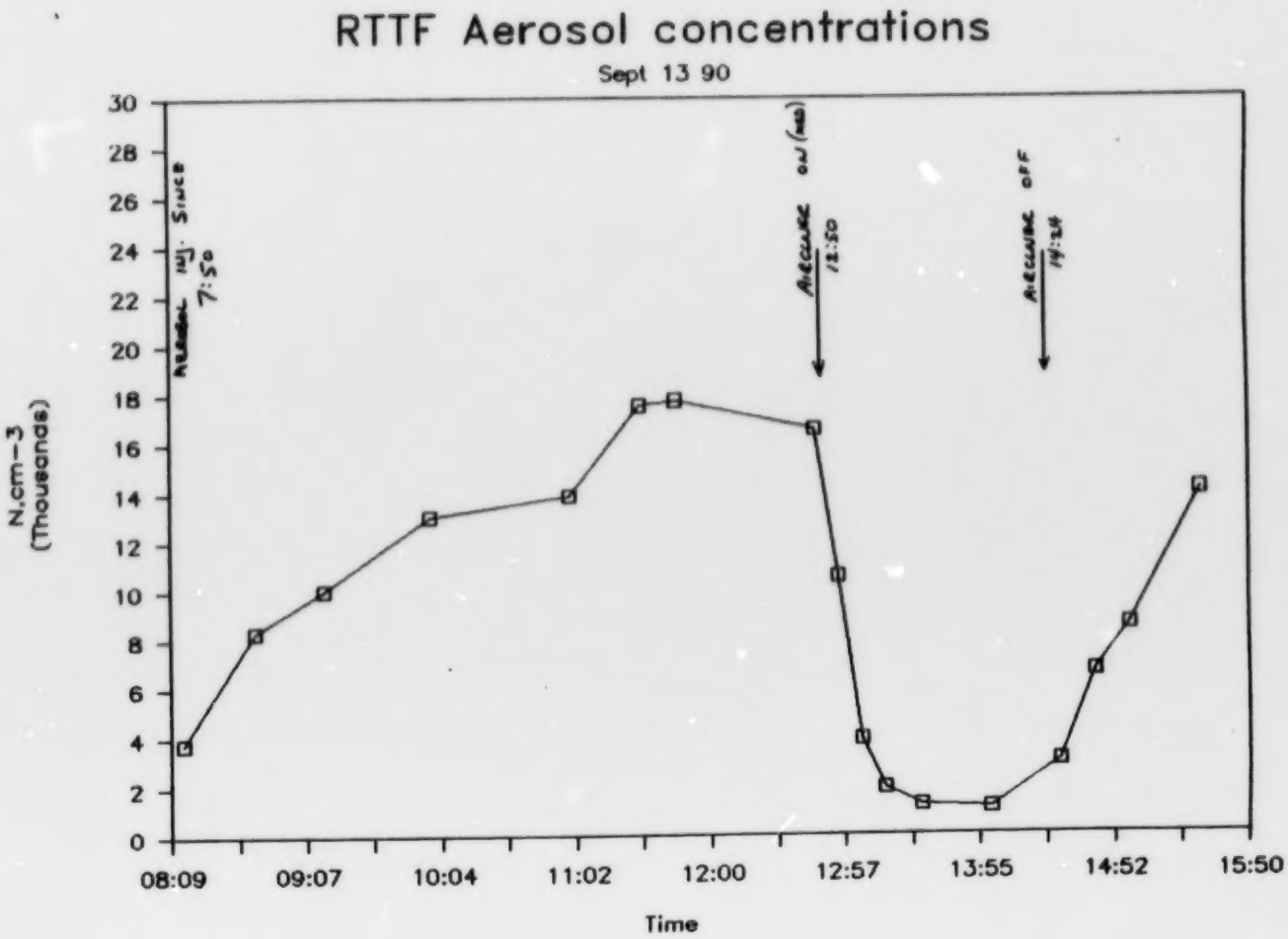

Fig. 3 - Aerosol concentration in the RTTF as a function of time. Vertical arrows indicate operating conditions.

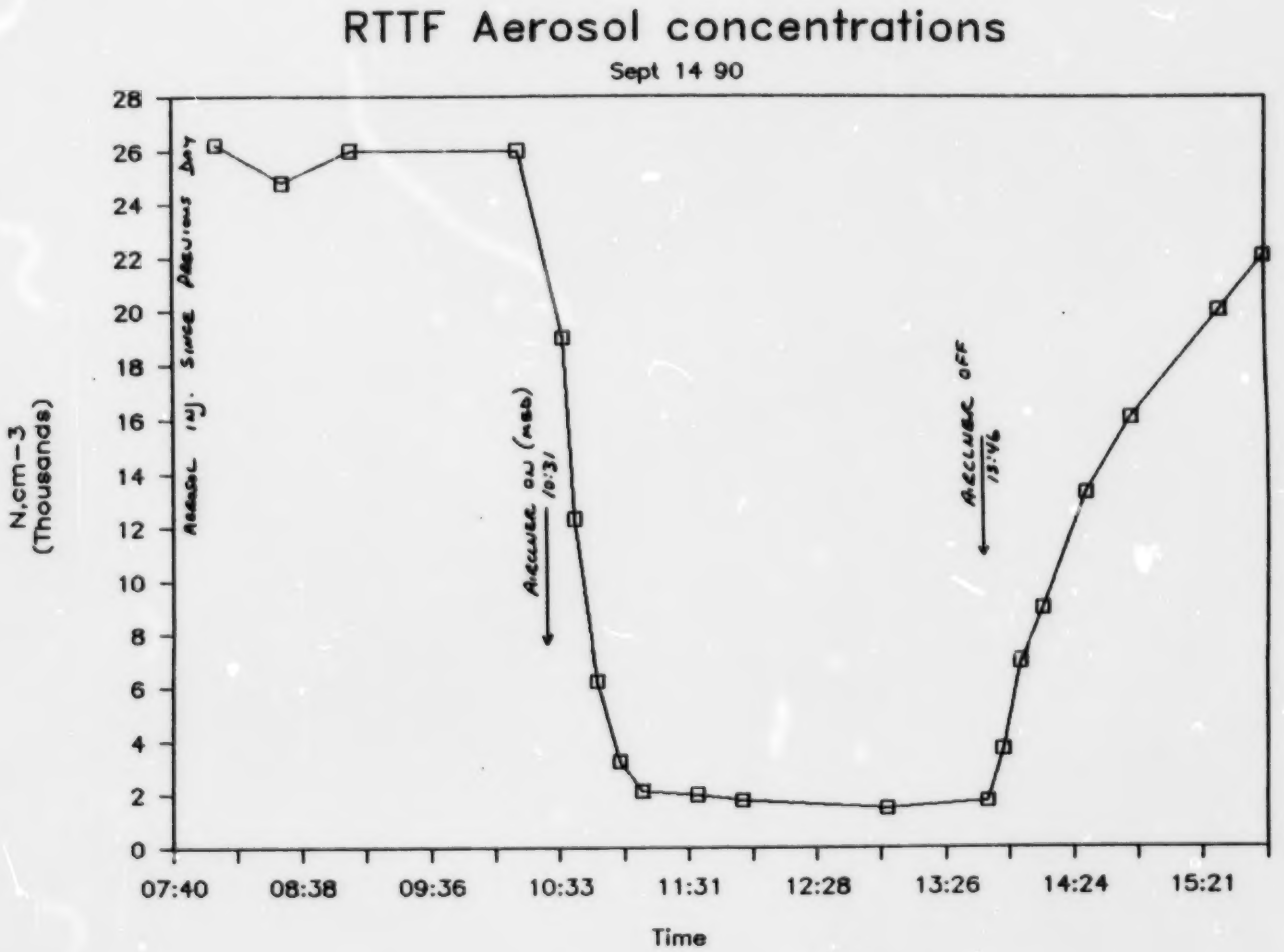

Fig. 4 - Aerosol concentration in the RTTF as a function of time. Arrows indicate operating conditions.

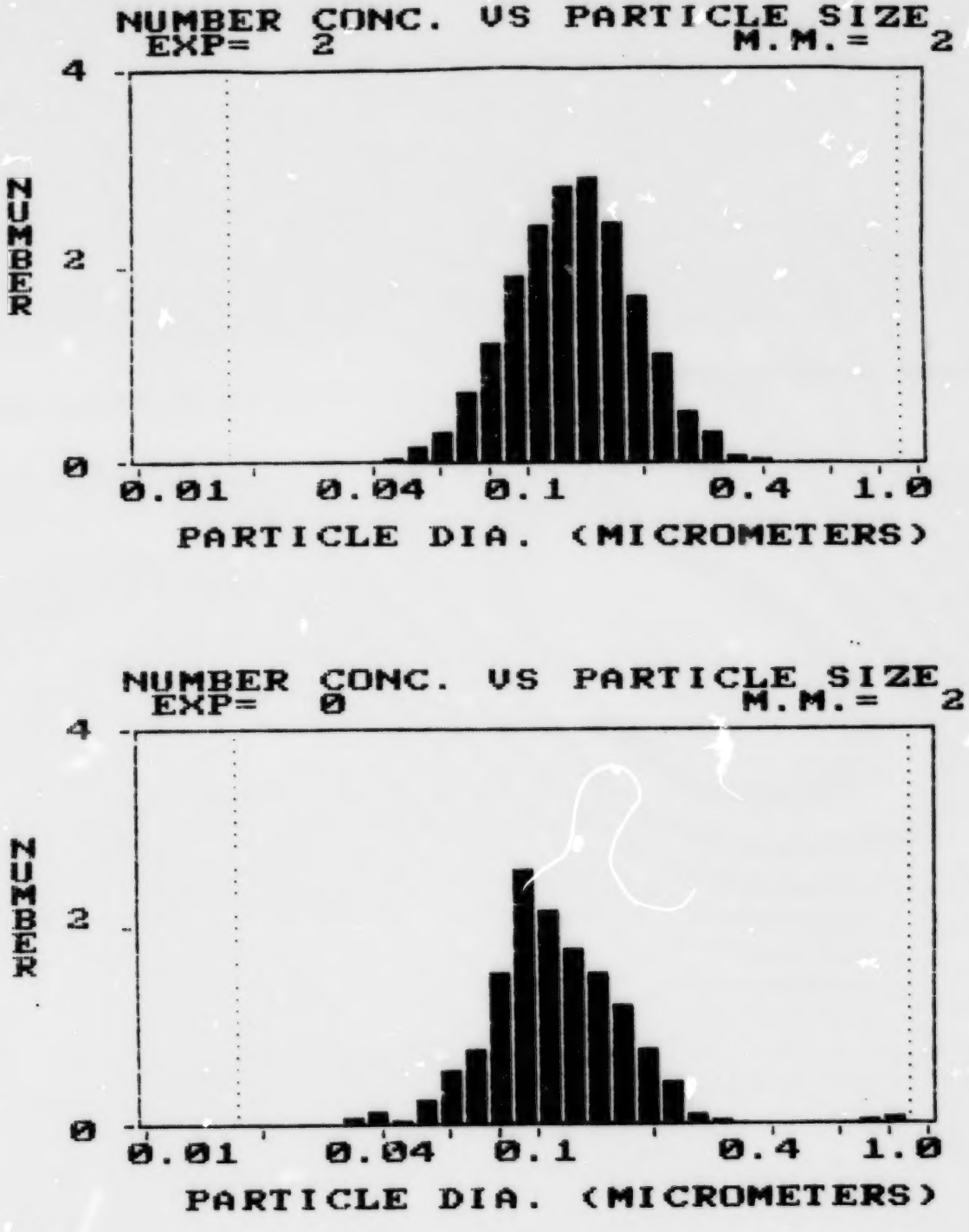

Fig. 5 - Aerosol size distribution in the RTTF when the air cleaner is not operating (upper graph), and during operation of the device

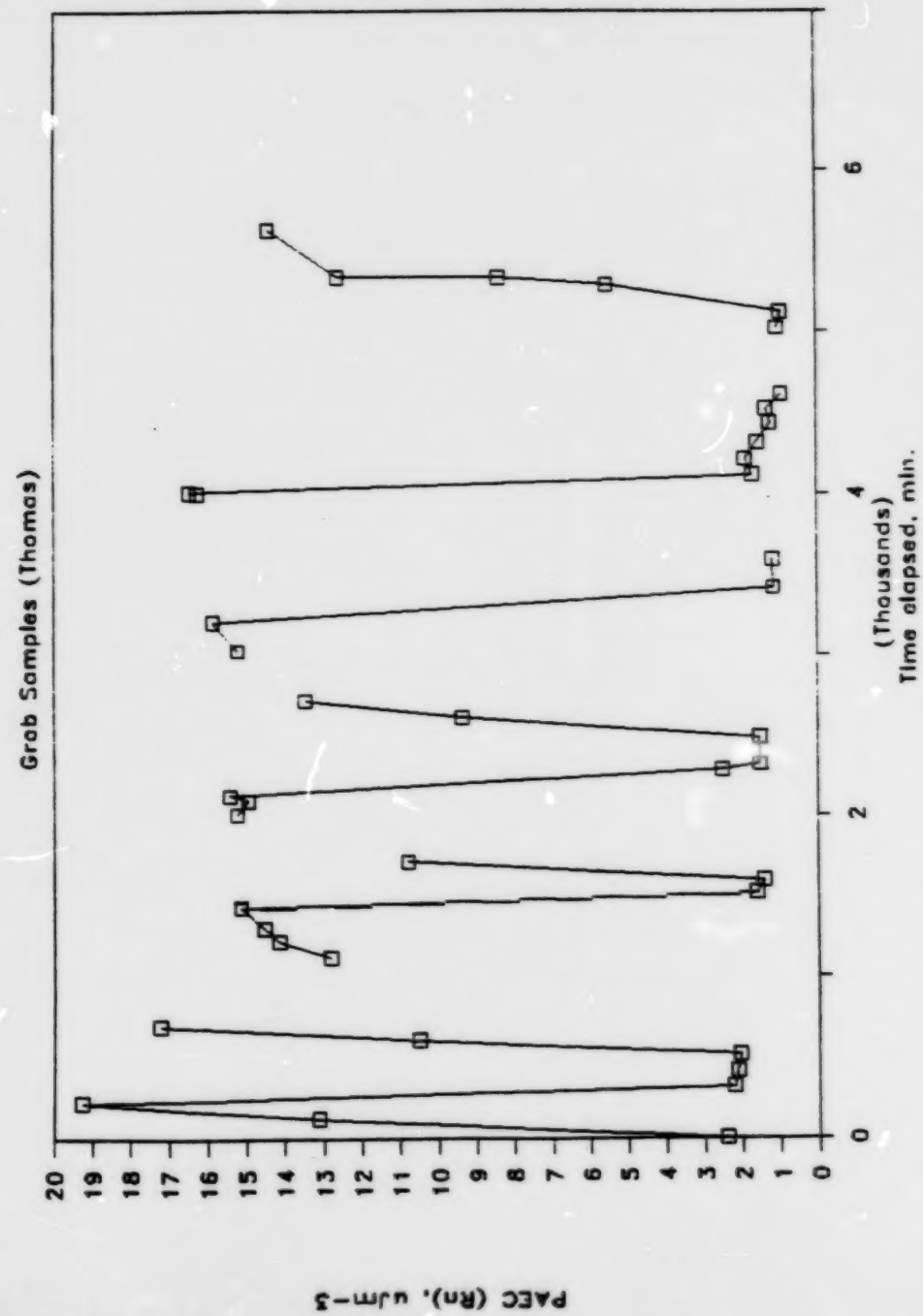

Fig. 6 - PAEC(Rn) versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in PAEC(Rn) are indicative of the air cleaner turned on (decrease) or off (increase).

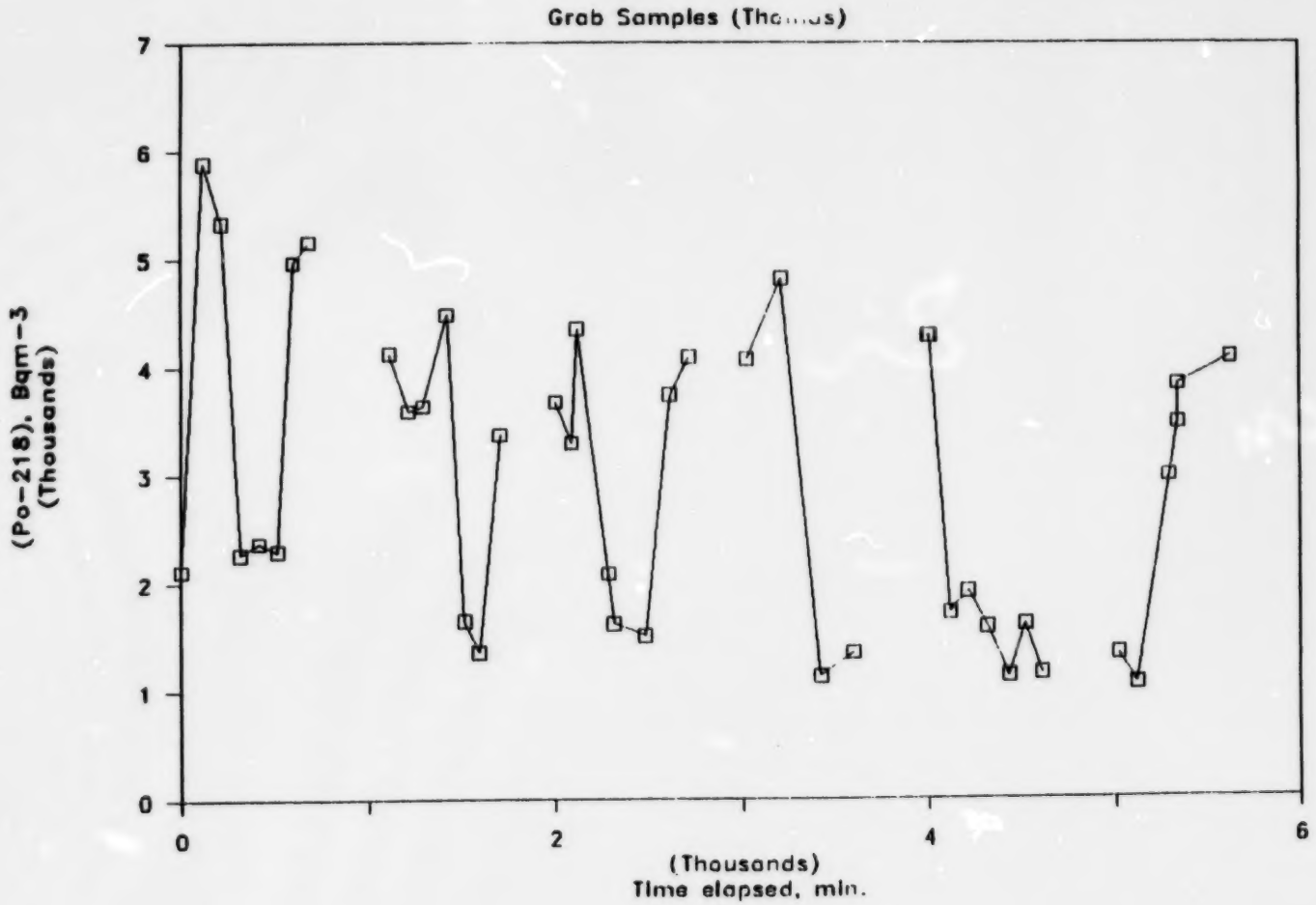

Fig. 7 - ^{218}Po versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in ^{218}Po are indicative of the air cleaner turned on (decrease) or off (increase).

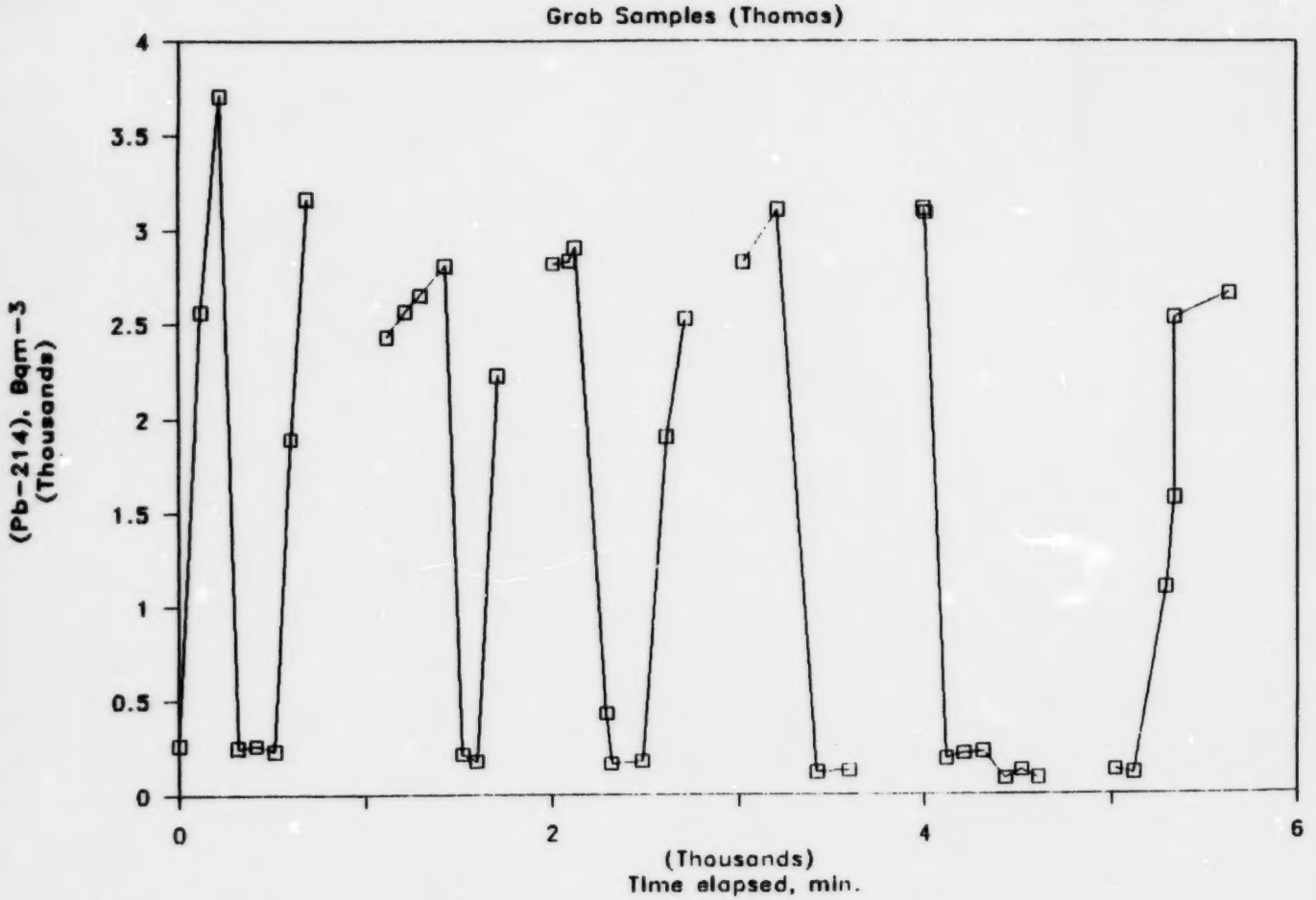

Fig. 8 - ^{214}Pb versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in ^{214}Pb are indicative of the air cleaner turned on (decrease) or off (increase).

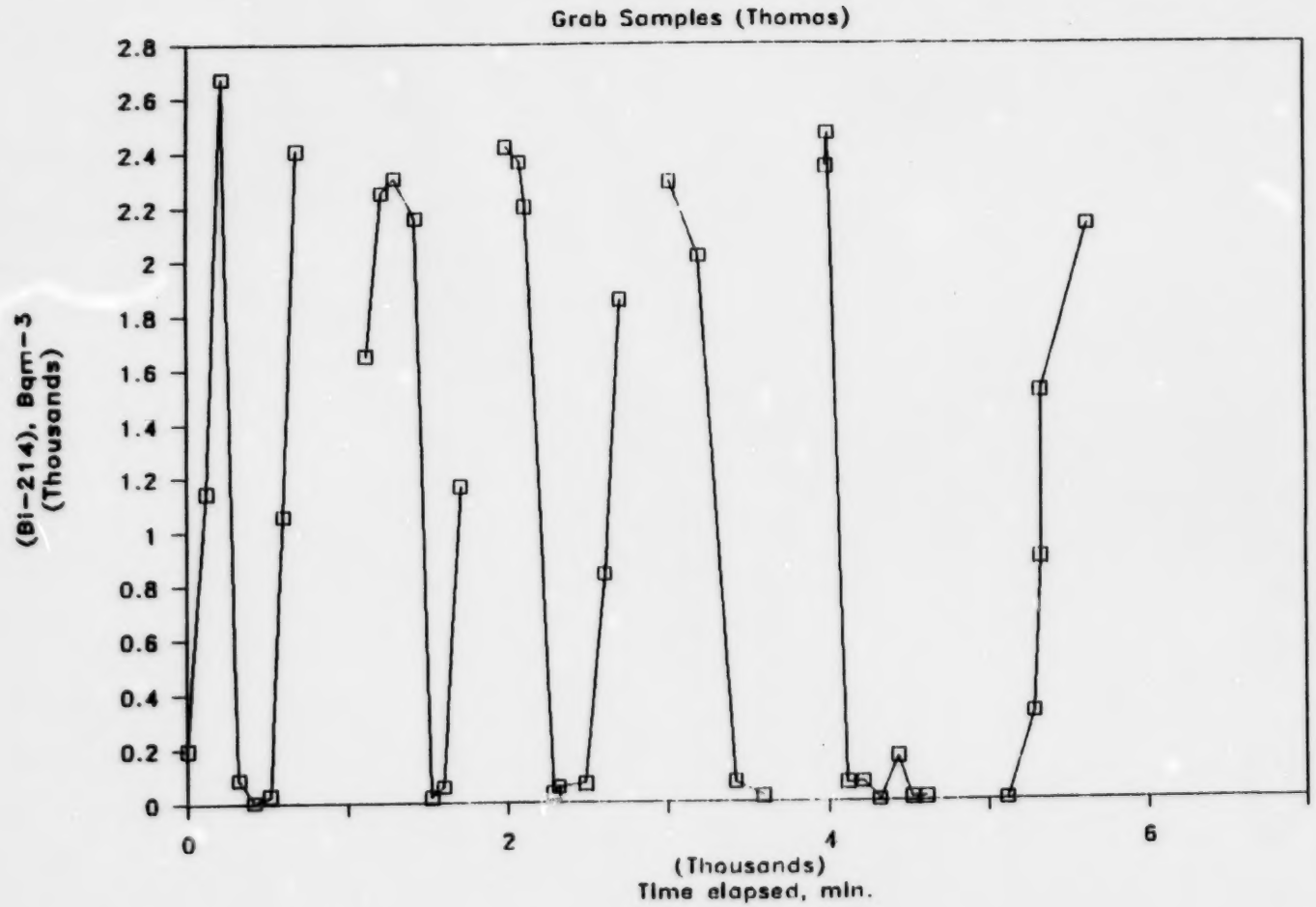

Fig. 9 - ^{214}Bi versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in ^{214}Bi are indicative of the air cleaner turned on (decrease) or off (increase).

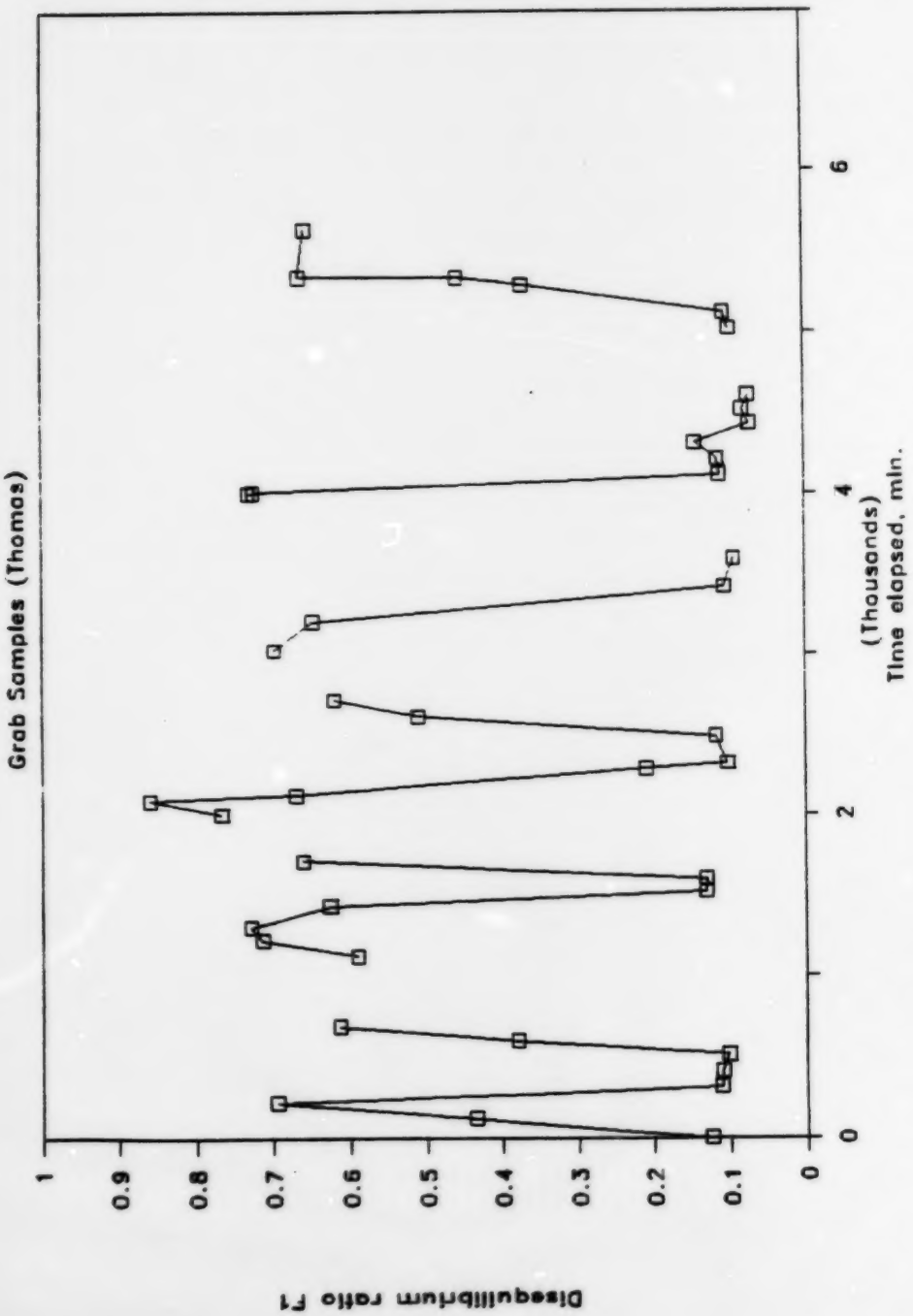

Fig. 10 - Disequilibrium ratio $[^{214}Pb]/[^{218}Po]=F1$ versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in F1 are indicative of the air cleaner turned on (decrease) or off (increase).

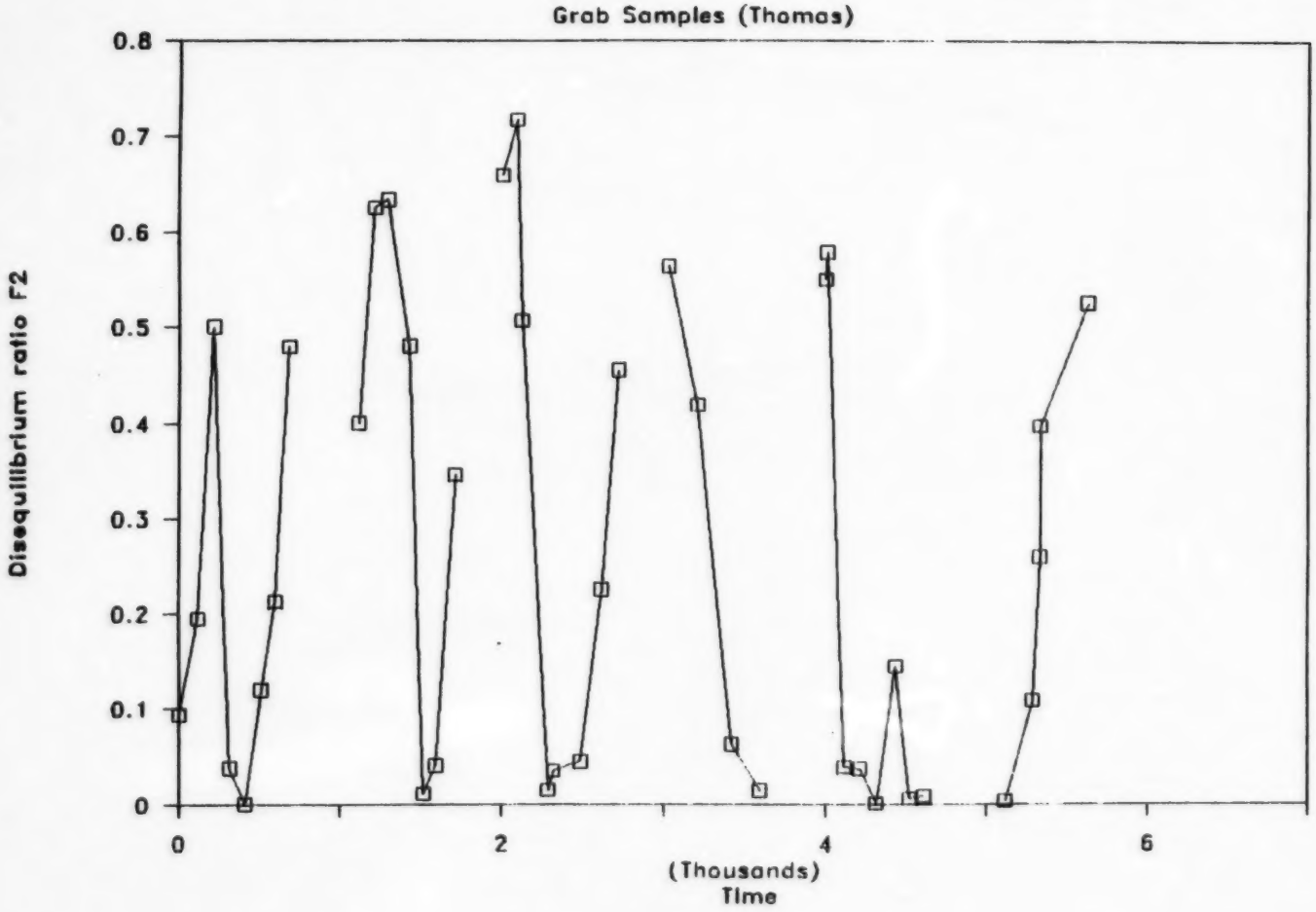

Fig. 11 - Disequilibrium ratio F2 = $[^{214}Po]/[^{218}Po]$ versus time for six different experiments (days). The tracers are separated by blank spaces for clarity. Abrupt changes in F2 are indicative of the air cleaner turned on (decrease) or off (increase).

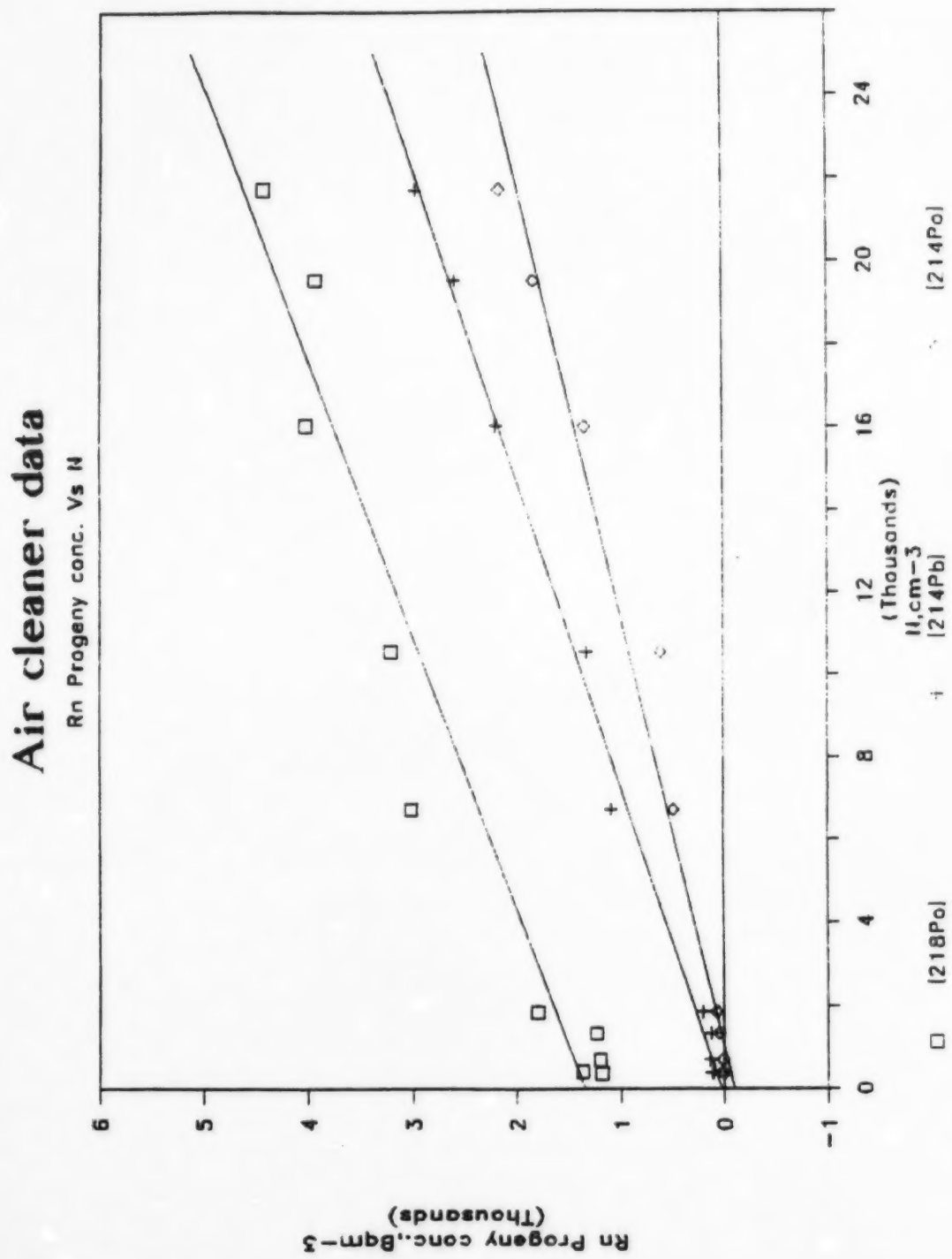

Fig. 12 - ^{222}Rn progeny concentration versus aerosol concentration.

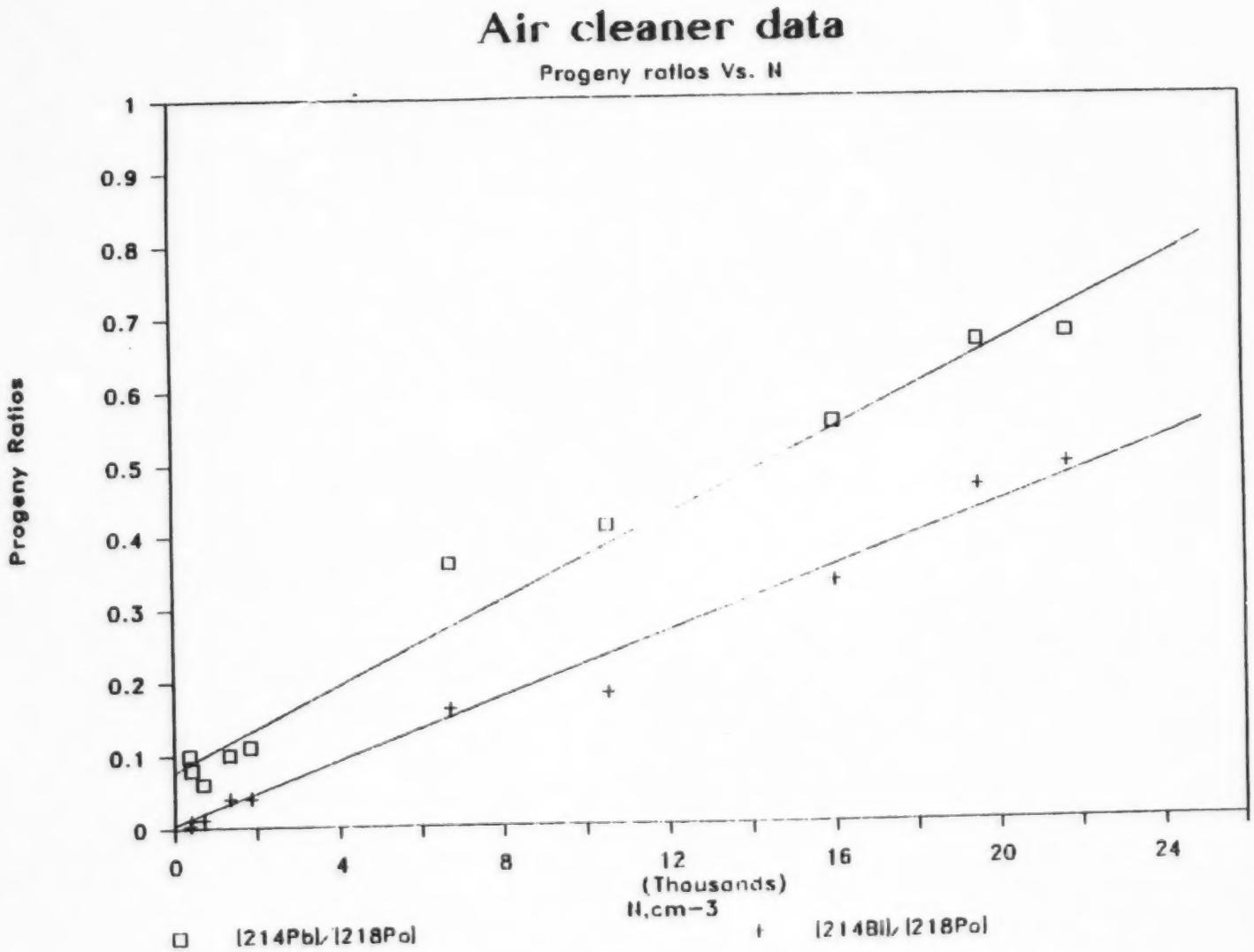

Fig. 13 - ^{222}Rn progeny ratios F1 and F2 versus aerosol concentration.

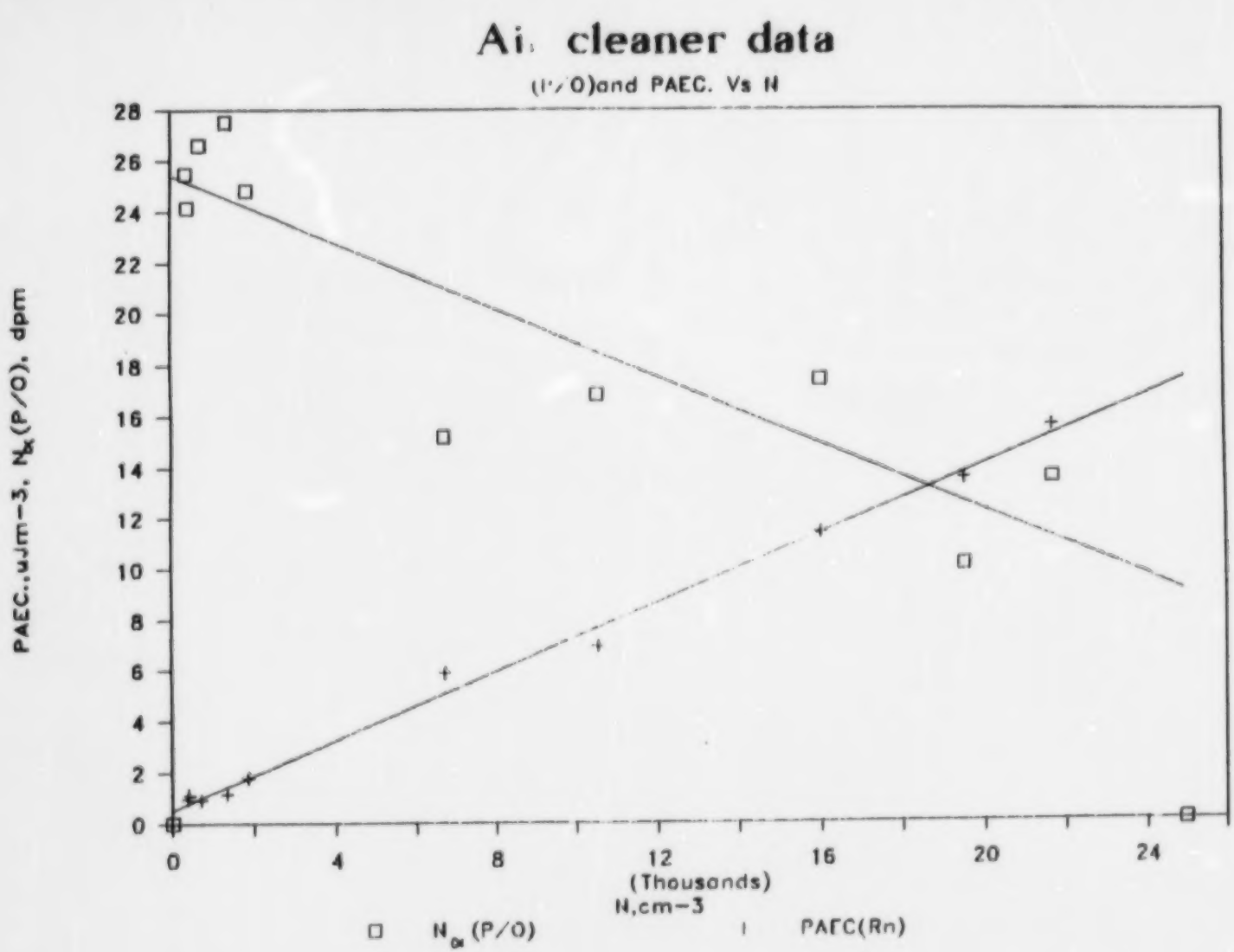

Fig. 14 - PAEC(Rn) and plate-out activity, N_α(P/O), versus aerosol concentration.

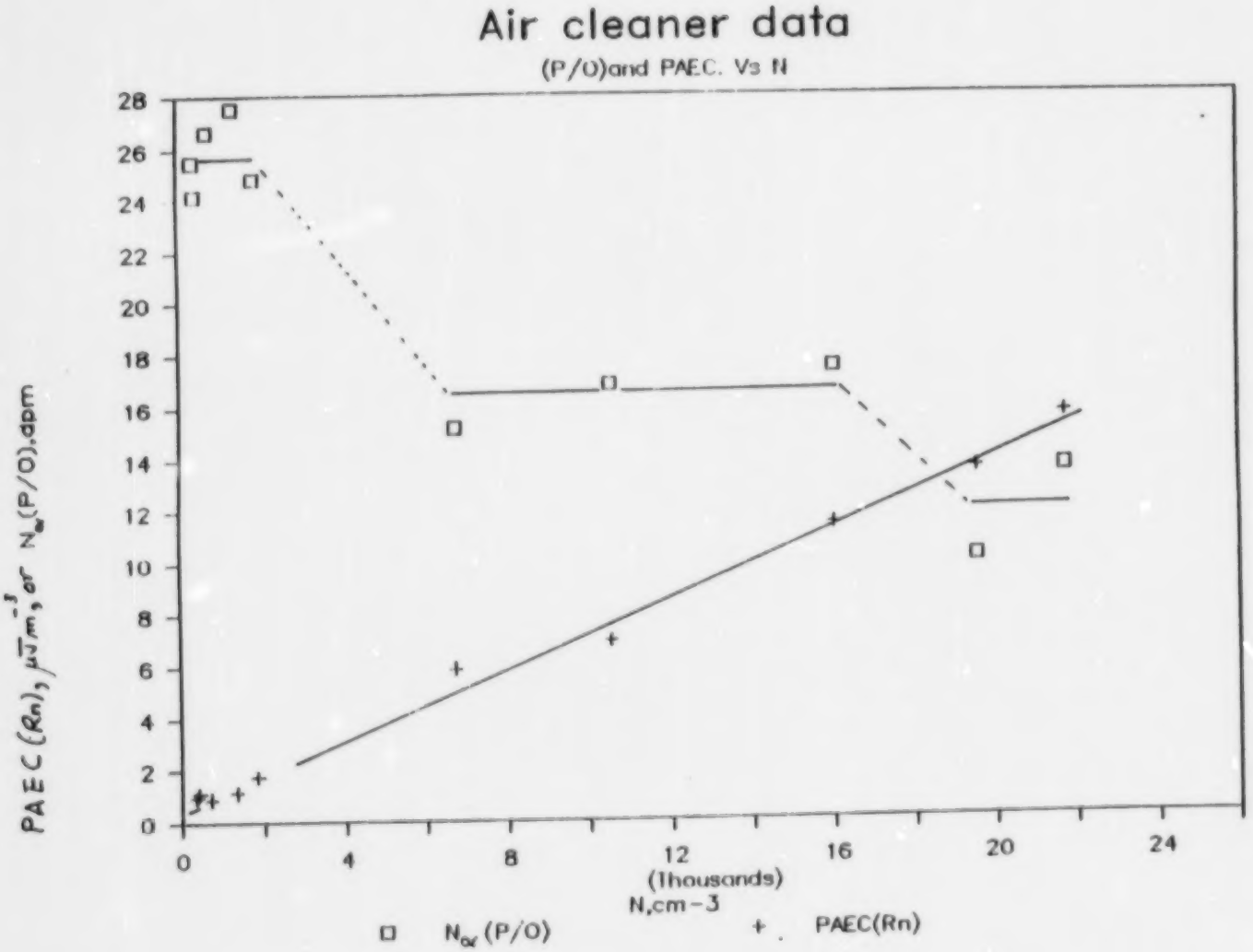

Fig. 15 - PAEC(Rn) and plate-out activity, $N_{\alpha}(P/O)$, versus aerosol concentration.

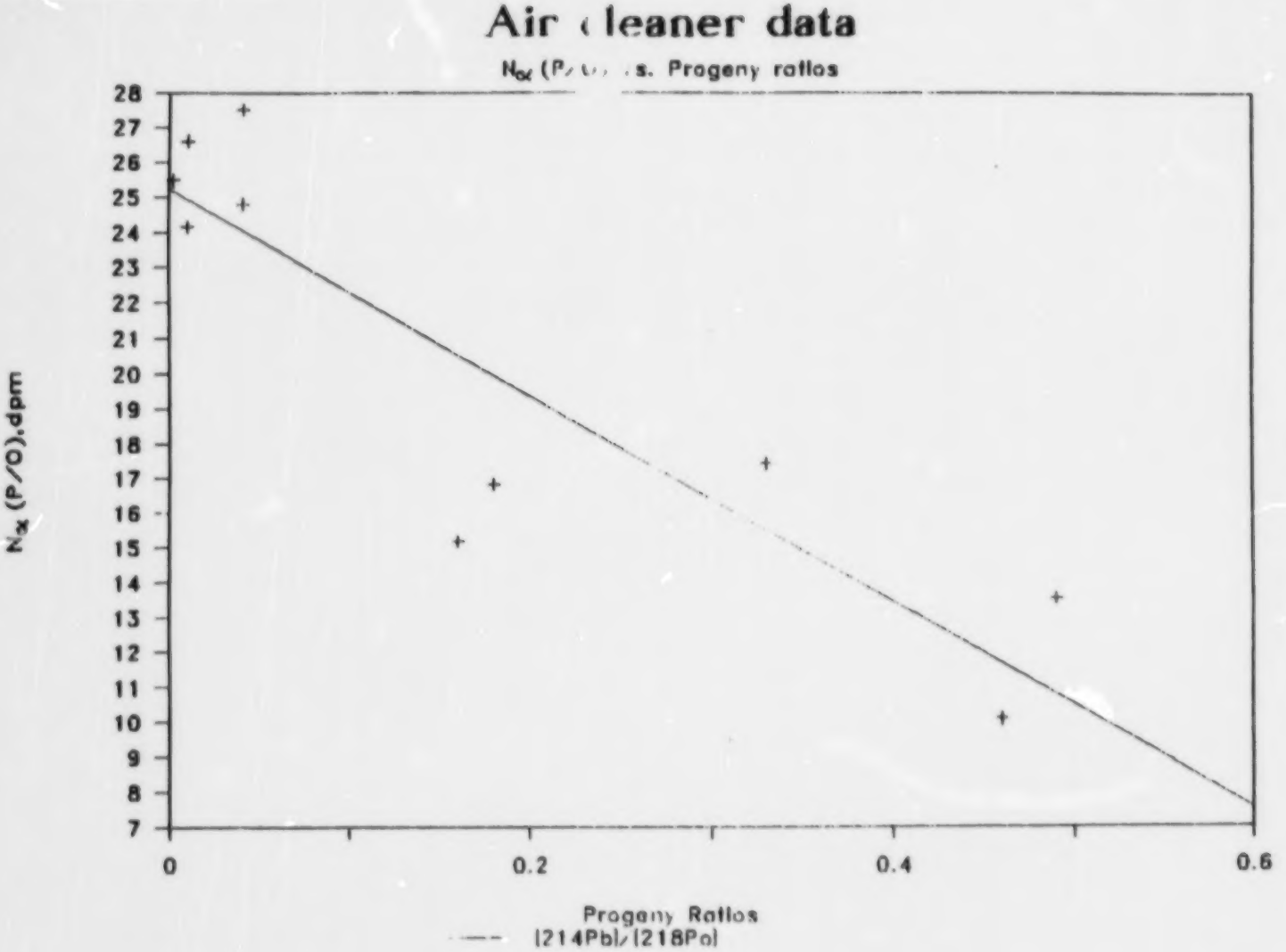

Fig. 16 - Plated-out α-particle activity, $N_\alpha(P/O)$, versus ^{222}Rn progeny disequilibrium ratio F1.

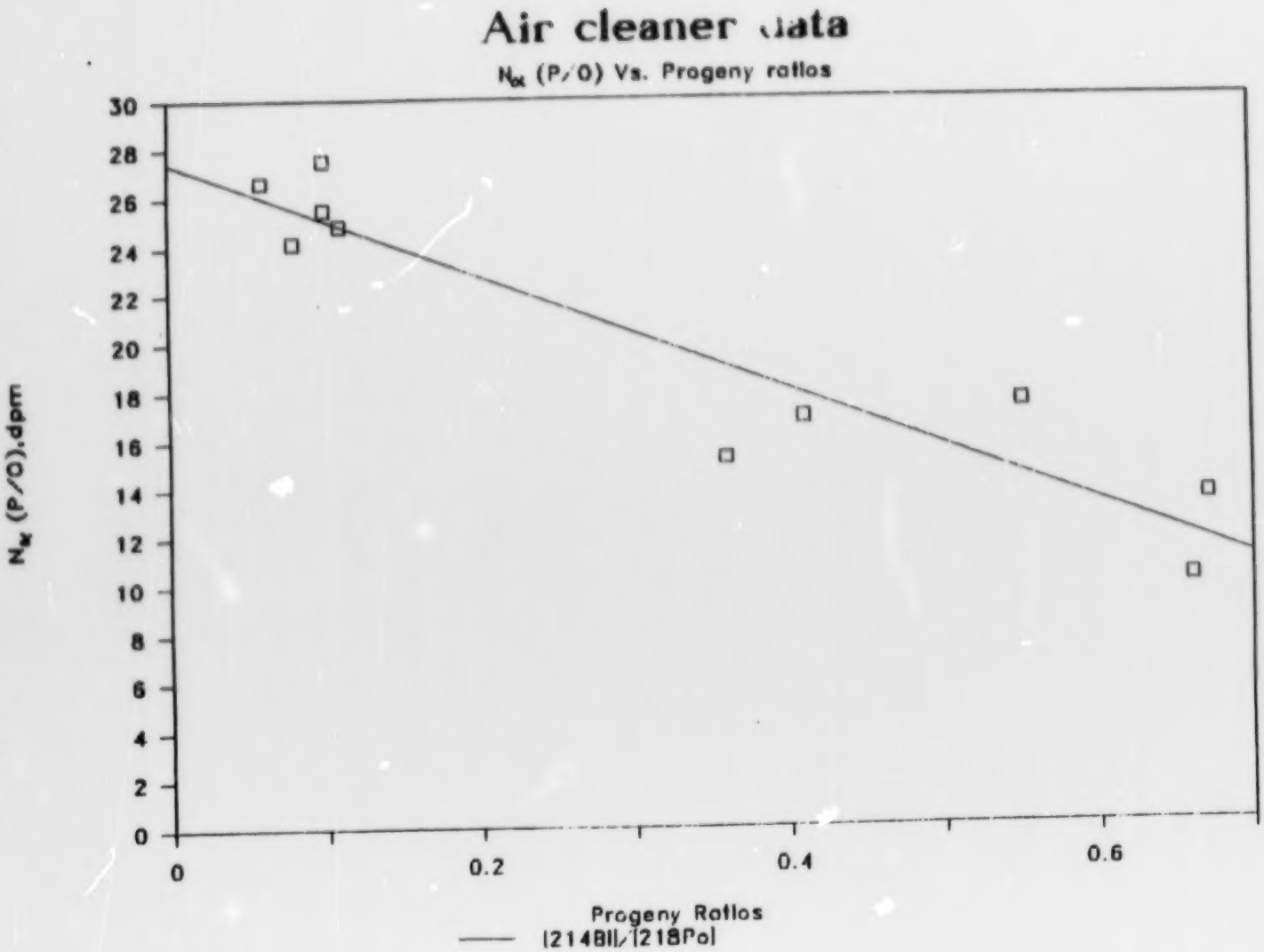

Fig. 17 - Plated-out α-particle activity, $N_{\alpha}(P/O)$, versus ^{222}Rn progeny disequilibrium ratio F2.